NATIONAL BUREAU OF STANDARDS REPORT

7536

Development, Testing, and Evaluation of Visual Landing Aids
Consolidated Progress Report for the Period April 1 to June 30, 1962

By
Photometry and Colorimetry Section
Metrology Division

U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

THE NATIONAL BUREAU OF STANDARDS

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The results of the Bureau's research are published either in the Bureau's own series of publications or in the journals of professional and scientific societies. The Bureau itself publishes three periodicals available from the Government Printing Office: The Journal of Research, published in four separate sections, presents complete scientific and technical papers; the Technical News Bulletin presents summary and preliminary reports on work in progress; and Basic Radio Propagation Predictions provides data for determining the best frequencies to use for radio communications throughout the world. There are also five series of nonperiodical publications: Monographs, Applied Mathematics Series, Handbooks, Miscellaneous Publications, and Technical Notes.

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NATIONAL BUREAU OF STANDARDS REPORT

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7536

Development, Testing, and Evaluation of
Visual Landing Aids

Consolidated Progress Report
to
Ship Aeronautics Division
and
Meteorological Division
Bureau of Naval Weapons
Department of the Navy

and to
Federal Aviation Agency
Washington 25, D. C.

For the Period
April 1 to June 30, 1962

U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

Development, Testing, and Evaluation of Visual Landing Aids
April 1, 1962 to June 30, 1962

I. REPORTS ISSUED

Report No.	Title
7519	Development, Testing, and Evaluation of Visual Landing Aids, Consolidated Progress Report for the Period October 1 to December 31, 1961
7522	Development, Testing, and Evaluation of Visual Landing Aids, Consolidated Progress Report for the Period January 1 to March 31, 1962
21P-62/61	Physical and Electrical Tests of Connector Kits for Airport Lighting Cable, Manufactured by the Elastimold Division, Elastic Stop Nut Corporation of America
21P-2/62	Photometric Tests of a Type MC-2a Prismatic-Type Approach and Runway Light Manufactured by Multi Electric Manufacturing, Inc.
21P-23/62 Letter Report	Insulation Resistance of a No. 18047 Line-Up Guide Light Manufactured by Structural Electric Products Corp.
21P-24/62	Photometric Tests of a Modified DCB-10 Beacon Manufactured by Crouse-Hinds Company
21P-24/62 Supp.	Supplemental Photometric Tests of a Modified DCB-10 Beacon Manufactured by Crouse-Hinds Company
21P-25/62	Tests of a Type AL-1 Flush Approach Light Unit Manufactured by Crouse-Hinds Company
21P-39/62	Photometric Tests of a No. 18047 Line-Up Guide Light Manufactured by Structural Electric Products Corporation
21P-40/62	Intensity Distribution Measurements of a Condenser-Discharge TV-Tower Light Manufactured by Electronic Lights
21P-49/62	Photometric Measurements of a Flush/Frangible Flasher Manufactured by Sylvania Electric Products, Inc.

II. VISIBILITY METERS AND THEIR APPLICATION

Slant Visibility Meter. The data on hand from the slant visibility meter have not been sufficiently evaluated to determine adequately the relationship between the SVM records, the observed visual ranges, and slant visibility. A mathematician has been employed to evaluate this data. Preliminary analysis indicates that additional visual observations are needed for comparison. In order to reduce the delay in preparing the tower for test observation when suitable fog conditions exist, the threshold lights and visibility targets have been permanently mounted on the tower, although the tower still telescopes to reduce the height of the obstruction. Obstruction lights have been installed atop the tower.

Review of Transmissometer Manual. The Manuals T.O. 31M1-2GMQ10-61 NAVWEPS 50-30GMQ10-2 Operations and Service Instructions and T.O. 31M1-2GMQ10-63 NAVWEPS 50-30GMQ10-3 Overhaul Instructions for Model AN/GMQ-10B and Model AN/GMQ-10C transmissometers were reviewed for errors and omissions. A number of errors, incorrect statements, and omissions which could result in confusion or in following incorrect procedures were noted. After completion of the cross checking of these manuals with NBS Report No. 2588 (Revised), the discrepancies will be tabulated for use in preparing future revisions of these manuals.

Transmissometers. The Weather Bureau has installed a transmissometer set at the Arcata Airport near the touchdown area of runway 31. This installation is to be used for determining runway visual range (RVR) for this approach. The Weather Bureau is awaiting delivery and installation of the computer unit before activating this equipment. The rotating-beam ceilometer cannot be located at the site in the approach zone originally selected by the Weather Bureau and the status of this installation is uncertain. The National Bureau of Standards Field Laboratory has been authorized to take the signal from the transmissometer installed by the Weather Bureau to one of our indicators for our use. Because the Weather Bureau transmissometer is in the same area as transmissometer T-D, T-D has been removed.

The sensitivity of transmissometer T-A was decreasing gradually but would recover part of the loss in sensitivity when the unit was de-energized for inspection and maintenance. The defective component was found to be the phototube, type 919, which was showing the effects of fatigue.

A transmissometer has been shipped from Washington to the University of California, Berkeley, for use in the fog chamber being constructed there.

The Effect of High-Intensity Airport Lighting on Background Luminance and Horizontal Illumination. The paper entitled "Horizon Sky Brightnesses Produced by Airfield Lighting" was completed. This paper presents the results of measurements of the brightness of the sky near the horizon from environmental lights and from high-intensity runway and approach lights. Values of horizon sky brightness from environmental lights of 0.0005 to 0.2 foot-lamberts were measured. The high-intensity lights increased the

brightness of the sky near the horizon by as much as 0.5, 5, and 50 foot-lamberts, respectively, for type M-2 runway lights, slopeline approach lights, and centerrow approach lights. The effects of these brightnesses on the minimum illumination required for detection of point sources are discussed.

Shipboard Visibility Meter. Reconstruction of the instrument has been completed. In the reconstructed instrument the photomultiplier is continuously exposed to sky light instead of being gated as in the original design. This has eliminated the pulse, produced by the gated sky light during the daytime, which was over-riding the signal. However, the integral of the a-c noise produced by bright daylight between flashes is too large to permit recording of the signal although the signal can be read when displayed on an oscilloscope. The unit will be modified to gate the noise signal between the flashes of the light so that it will not contribute to the over-all signal.

A sensitive a-c amplifier has been obtained for use as a pre-amplifier between the photomultiplier of the receiver and the integrator of the pulse signals received.

A second method of display of the output of the instrument is being considered. This method utilizes a circuit recently developed by Suga, Clark, and Escobar. The output of this circuit is a pulse whose duration is proportional to the input pulse amplitude over a range of 4 decades. This output could be displayed on an oscilloscope or could be integrated and used to drive a recorder. A breadboard unit of this type has been constructed so that the feasibility of using such an instrument can be tested.

III. DEVELOPMENT OF AIRFIELD LIGHTING AND MARKING COMPONENTS

Taxiway Lighting and Marking (TED NBS SI-5007). A proposed "Taxiway Lighting and Marking Guide" was prepared for the IES Aviation Committee Taxiway Lighting Subcommittee. This Guide contains recommendations for the lighting and marking of taxiways at airports for effective guidance. The recommended lighting employs edge-marker and centerline lights and taxiway guidance signs. The spacing and location of the lights and the location of the signs and information to be provided by the signs are discussed and shown in examples. The use of centerline, holding position, and edge markings is recommended. The major change from the design proposed for Miramar is the elimination of the extra light of the entrance-exit lights. This Guide will soon be revised as a proposed Navy standard for taxiway lighting.

Stub Approach Beacon and Counterrotating Beacon. A stub approach beacon has been installed on the approach to runway 13 at the Arcata Airport. This beacon is located on the extended centerline of the runway approximately 400 feet ahead of the runway threshold. The beacon is installed in a pit with only the lamps projecting above the ground level to minimize the effect of the beacon on the signal from the Instrument Landing System (ILS) localizer. To decrease the effect of the beacon on the localizer signal further and to provide a light shield from the end of the runway, a wooden plank covered with mesh wire and dirt was placed on the runway side of this beacon. This shield extends up to the height of the top of the lampholders and covers approximately 60 degrees on each side of the runway centerline. The six lamps are type 300 PAR56/SP lamps. Because control cables are not available from this site, the beacon operates continuously and is switched from high intensity in the daytime to low intensity at night by an electrical timer.

Although at this time of the year the winds seldom favor approaches to runway 13, several useful comments on the effectiveness of the stub approach beacon have been received. These comments indicate that this beacon is a useful visual aid for making circling approaches at night and may be still more valuable for making circling approaches in the more restricted visibility conditions. Since the visual approach slope indicator (VASI)*is also installed for approaches to this runway, the approach beacon is naturally compared with the VASI for effectiveness. The pilots state that the beacon is a valuable addition to the VASI for use on the downwind and base legs of the approach where adequate visual reference to the location of the end of the runway is lacking, but provides only minor improvement during the final approach. Some pilots think that if the intensity of the beacon were approximately equal to that of the VASI, the beacon might help in maintaining alinement during the final approach. The pilots recommend that the intensity of the beacon should be increased, that this beacon should be visible earlier on the downwind leg of the approach, that the tower should have energizing and intensity control of this beacon, and the vertical beamspread of the lamps should probably be greater.

Evaluation of the stub approach beacon will continue at least through the next winter. No tests of the counterrotating beacon are anticipated at this time.

The two approach beacons were shipped to the National Aviation Facilties Experimental Center for evaluation.

* formerly referred to as visual glide slope indicator (VGSI).

PAR-64 VASI Lamps. Initial photometric measurements were made on twelve off-focus PAR-64 VASI lamps submitted by three manufacturers for life test. The lamps were mounted individually in VASI lamp holders and each holder was adjusted for proper aim of the lamp beam. Each lamp will remain in its holder for the duration of the test to determine what changes, if any, occur in the intensity distribution and (relative) lumen output as the lamp is burned at rated current. NBS Test Reports 21P-22/62, 42/62 and 45/62 will be issued on completion of the life test of the lamps.

Chromaticity and Photometric Tests of VASI Filters. An assortment of filters for use in the VASI was received from Kopp Glass, Inc., including bottom sections of aviation-red and highway-crossing-red, top sections of aviation-white and a color-correcting white, as well as some full 360° roundels of two of the types. Chromaticity and photometric tests were made of several of the samples. A transmission ratio of more than 0.2 was obtained with the aviation-red and a ratio of more than 0.15 for the highway-crossing-red. The filters gave a beam spread of 18°(at 50% of peak intensity) and from 24° to 26° (at 10% of peak intensity) depending on whether the full 360° roundel was used on the test or only the segment when the beam spreads were measured using the regular VASI-type lamp. When a Type 4588 lamp, with a narrow beam spread approximating a collimated beam was used, the beam spread at 50% was the same and at 10% was 21°. NBS Test 21P-12/62 will be issued.

Flush/Frangible Light. Photometric measurements were made of a flush/frangible flasher unit manufactured by Sylvania Electric Products, Inc. The results of the tests are reported in NBS Test Report 21P-49/62.

Type MC-2a Prismatic-Type Approach and Runway Light. Test Report 21P-2/62 was issued giving the results of photometric tests of a Type MC-2a prismatic-type approach and runway light manufactured by Multi Electric, Incorporated, Chicago, Illinois. During the testing, some information was developed for improving the method for correcting for the difference between the photometric axis of a lamp and its geometric axis. Although the specification covering the light states that a correction shall be applied based on the deviation of the whole beam of the lamp, it appears that masking off part of the lamp area leaving only the area corresponding to the part accepted by the light is a better method. A limited number of applications indicate a better correlation by this method of correcting than was found by applying a correction based on the deviation of the whole beam.

Photometric and Life Test of 6000-Hour Obstruction Light Lamps. Initial photometric tests were started on eight developmental 6000-hour obstruction light lamps designed for 120-volt operation at 120 watts. This type lamp has an A-21 bulb, a medium prefocus base and a C-5 filament construction. The lamps will be given life tests and the results will be reported in NBS Test 21P-41/62.

Tests of a TV Tower Flashtube Light. Intensity distribution measurements were made of a condenser-discharge TV-tower light intended to perform photometrically like the three units currently in operation on a TV tower in Madison, Wisconsin. The unit was manufactured by Electronic Lights, Chicago 22, Illinois. The flashtube included with the unit was not identified as to manufacturer or type. The light is omnidirectional: a cylindrical Fresnel lens encloses the base-down flashtube. The effective intensity in the horizontal plane was determined at 30° intervals; the range was between 12.4 and 14.3 kilocandles. It was pointed out in the report issued, 21P-40/62, that the values obtained apply only to the laboratory model.

Effect of Filter Color on Location of Transition Zone in a Visual Approach Slope Indicator. With the availability of the Visual Approach Slope Indicator and a small assortment of red and white filters for the unit, study was continued on the effects of filter color on the pink visual transition zone of the indicator. Four combinations using aviation-red grade A, highway-crossing-red, aviation-white and a color-correcting-white (2854° to 4000°K) were mounted in the indicator and viewed at various elevations of the indicator by a group of observers. The observers then recorded their interpretation of the color: red, white, or pink. Several different techniques were tried and all seemed to indicate more variation between observers than between filter combinations. The project will be continued after the best technique is determined. The same technique will be used for each of the four possible combinations.

Intensity Control of Shore-Based Optical Landing System. The modification of the intensity control of the Shore-Based Optical Landing System at NATC, Patuxent River (see NBS Reports 7147, 7519, and 7522) was completed by NATC personnel. Difficulty was encountered, however, in the operation of the modified system, and NATC requested assistance in locating the fault. The system was inspected, and two minor changes were made in the wiring to correct the trouble.

In order to investigate the difference in brightness between the datum lights and the source lights which was originally reported, the bucking voltages of the modified system were reduced to zero. Voltage measurements on the "unmodified" system were then made by measuring the voltage on each brightness setting across the lamp terminals of one lamp in each of the six circuits. The measurements were then repeated with full buck voltage, 32 volts on step 7, applied to both sets of lights. The following table summarizes these measurements.

VOLTAGE MEASUREMENTS OF MODIFIED OPTICAL LANDING SYSTEM

Brightness Step	Datum Lights: Design Volts	Left Outboard (volts)	Left Inboard (volts)	Right Inboard (volts)	Right Outboard (volts)	Source Lights: Design Volts	Left Group (volts)	Right Group (volts)
		With Zero Volts Buck				With Zero Volts Buck		
7	115	116.5	115.5	115.0	115.0	11.5	9.3	10.0
6	80	81.2	82.0	81.0	81.0	8.0	6.7	6.9
5	60	61.2	61.4	60.6	61.0	6.0	4.75	5.0
4	45	46.1	46.1	45.5	45.6	4.5	3.4	3.65
3	35	35.5	35.5	35.0	35.2	3.5	2.6	2.75
2	27.5	27.3	27.2	26.9	27.0	2.75	2.0	2.0
1	20	20.0	20.1	19.8	19.9	2.0	0.9	1.0
	With 32 Volts Buck on Step 7 *					With 3.2 Volts Buck on Step 7 **		
7	83	84.5	84.6	84.0	84.0	8.3	8.4	8.52
6	58	59.0	59.0	58.7	58.5	5.8	6.0	6.1
5	43	44.0	44.0	43.2	44.0	4.3	4.19	4.2
4	33	33.2	33.0	32.5	32.7	3.3	3.1	3.1
3	25	25.6	25.6	25.2	25.2	2.5	2.45	2.4
2	19.9	20.0	20.0	19.8	20.0	1.99	1.70	1.70
1	14.4	14.3	14.2	14.0	14.1	1.4	0.7	0.9

* Buck voltage was adjusted until there were 84.5 volts across left outboard lamp.

** Buck voltage was adjusted until there were 8.4 volts across left group lamp.

As can be seen from the measurements on the "unmodified" system (with zero volts buck), the voltages on the source lights are too low by an amount which makes them operate approximately one brightness step lower than the datum lights. A possible reason for this voltage drop is the location of the 10:1 step-down transformer. If it is located near the vault, full lamp current would have to flow from the vault to the distant lights, and the line drop would be approximately 10 times as great as if the transformer were located at the source lights. NATC personnel were to determine the cause of the low source-light voltage.

Output Maintenance of Sealed-Reflector Approach and Runway Light Lamps. The photometric measurements as part of the study of the output maintenance characteristics of sealed-reflector 6.6-ampere and 20-ampere approach and runway lamps (see NBS Reports 6940, 6941, 7027, 7104, and 7147) have been completed. The lamps were burned in both vertical and horizontal positions, and the relative output was measured periodically both of the complete lamps and of selected zones of the lamps. Evaluation of the data is being carried out.

Automatic Intensity Control of Approach and Runway Light Systems. (TED NBS SI-5004). Further consideration has been given to the design of an automatic intensity control system which would be controlled by an RVR computer. A satisfactory simple design was developed for daylight conditions. However, difficulty was encountered in designing for night time conditions because the RVR computer indicates all runway visual ranges above 6000 feet as 6000 + and a change from step 1 to step 2 and possibly to step 3 is required at a visual range greater than 6000 feet. This difficulty could be readily overcome by a modification of or an addition to the RVR computer. In the meantime the design of an automatic control system based on the expanded-scale transmissometer indicator and a system of relays has been completed and the required components obtained. Construction will be started next quarter.

IV. DEVELOPMENT OF SEADROME LIGHTING COMPONENTS

No work has been done on this task during the quarter.

V. DEVELOPMENT OF CARRIER LIGHTING AIDS (TED NBS RSSH-32001)

Photometric Tests of a Pancake Light for Shipboard Use. Photometric tests of a "No. 18047 line-up guide light" manufactured by Structural Electric Products Corporation, Windsor Locks, Connecticut, were completed and NBS Test Report 21P-39/62 was issued. Letter report 21P-23/62 had been issued previously giving the results of insulation resistance measurements made of the unit. The unit was an open type pancake light with a 45-watt quartzline lamp.

Helicopter Angle-of-Approach System for Carriers. A trip was made to the Naval Air Material Center, Philadelphia, to inspect the completed model of an experimental helicopter angle-of-approach light. This model consists of the four carrier approach lights which had been modified at the National Bureau of Standards and shipped to the Naval Air Material Center to be assembled into a working unit. (See NBS Report No. 7384). The lights have been mounted on a stabilized turntable covered with a plexiglass dome. After the inspection it was recommended that the arrangement of the optical components of the lights be restored to that used by NBS and that baffles be installed between the lights and below the turntable to intercept the reflections from the plastic dome.

Off-Glide-Path Indicator. The Fresnel Lens Assembly with the attached experimental High-Low cells is being set up on an outdoor range for observation under operational conditions. (See NBS Report 7384).

Consultive Services. Technical advice and assistance have been given on several problems related to optical landing systems, such as methods of correcting the deficiencies in the cross-light system, use of red filters in the lower cells of the Fresnel system, etc.

VI. PHOTOMETRIC AND ELECTRICAL TESTS OF AIRFIELD AND SEADROME LIGHTING COMPONENTS (TED NBS SI-5003)

Type AL-1 Flush Approach Light. Tests were made on a Type AL-1 flush approach light unit manufactured by Crouse-Hinds Company, Syracuse 1, New York. The unit met the photometric requirements of Specification FAA-1199a. The unit was further tested for: (1) dead loading (no damage); (2) watertightness (satisfactory); (3) 24-hour operation (satisfactory); (4) dimensions (satisfactory except for ambiguity in specification); (5) thermal shock (no damage); (6) insulation resistance (satisfactory). The stainless steel used was found to be as specified; there were some deficiencies found in the gaskets supplied with the unit. NBS Test Report 21P-25/62 was issued.

Photometric Tests of a Modified DCB-10 Beacon. Photometric tests were continued for determining the effective intensity of a modified DCB-10 beacon manufactured by Crouse-Hinds Company, Syracuse, New York. The modification consisted mainly of substituting a 1200T20 1200-watt lamp for the 500T20/13 500-watt lamp for which the light was designed. The unit had a peak effective intensity of 15.4 kilocandles with a vertical beam spread of 15° at 50% of peak intensity, assuming a rotation rate of 15 rpm. NBS Test Report 21P-24/62 was issued. A chart was included showing the effect of changing the rate of rotation.

The unit was further modified at NBS to accommodate a 1M/T20BP 1000-watt lamp to study the effects of a more compact filament configuration. NBS Test Report 21P-24/62 Supplementary was issued, showing a 39.2 kilocandle peak effective intensity for the unit, with a 4° vertical beam spread at 50% of peak intensity. Again a rotation rate of 15 rpm was assumed.

Frangible Couplings. Frangible couplings with modifications designed to make removal of the stub from the base covers easier have been tested. The stubs are easier to break out if a groove is formed on the inside of the coupling from just below the breakoff notch to the bottom of the coupling. This groove should be at least 1/8-inch wide and located at a corner of the hexagon. The groove should be as deep as possible without reaching the threads of the coupling. The metal in some of the couplings is such that the break is along the notch as it should be. However, the metal of some of the couplings which were procured earlier was non-uniform with hard spots, which caused the break to extend well outside of the notch. The metal should be suitable for a proper breakoff. A rough draft of a report on this work has been prepared.

Airfield Lighting Connectors Field Tests. Some of these connectors have been buried three years and others for two years. Only one connector has shown any definite indication of increased leakage over that at the start of the test. A ground resistance tester is being procured to determine better the effect of soil resistance on the leakage of these connectors.

Lamp Characteristics. A supplement is being prepared for NBS Report No. 6190, Current-Intensity, Voltage-Intensity and Current-Voltage Characteristics of Airfield Lighting Lamps, which was issued in October 1958. As reported in NBS Report No. 7522, measurements were made during the first quarter of this year of the characteristics of lamps developed since NBS Report No. 6190 was issued. The data from the measurements are being prepared for the supplementary report.

VII. MISCELLANEOUS TECHNICAL AND CONSULTIVE SERVICES

Review of Specifications and Drawings. The technical sections of the following specifications and drawings were reviewed and the comments have been forwarded.

MIL-T-4663B	Transmissometer Set AN/GMQ-10 Specification
(Proposed draft)	Connector Kit Specification
Y&D Dwg. No. 894982	Runway Distance Marker, Plan and Installation Details
Drawing SE 136 10.1-1	Centerline Approach Light System
FAA	Installation Criteria for Narrow Gage and Centerline Runway Lights

Lighting and Marking of TV Towers. Assistance has been given the project officer and contractor in the analysis of the data obtained to date in the field tests of lighting and marking systems for tall towers and in the planning of future activities.

Review of Literature. The revised draft of a supplementary report of operational tests and human factors research and a related annotated bibliography prepared for the FAA by Human Sciences Research, Inc. have been critically reviewed and discussed with representatives of the contractor.

I.C.A.O. Activities. Meetings of working groups preparing documentation for the U.S. position for the second meeting of the Visual Aids Panel and the seventh meeting of the AGA Division have been attended and pertinent material has been prepared. In fulfilling the obligations of CIE representative we have prepared material pertinent to the control of the intensity of approach and runway light systems and the determination of runway visual range and sent it directly to the Secretariat.

Other. Technical advice and assistance has been given a local firm in establishing a photometric laboratory for the qualification testing of aviation ground lights.

VIII. MISCELLANEOUS

Personnel. Weston W. Williams entered on duty as a mathematician on June 12. He will be working only through this summer, primarily on evaluating the data obtained from the slant visibility meter. Robert T. Vaughan returned to duty on April 30, after an extended period of sick leave. Austin S. Brown entered on duty May 29, as a student assistant electrical engineer.

Arcata Airport Cable Failure. A cable serving as a 2400-volt primary feeder failed. This cable was standard 5000-volt airfield lighting cable. The fault developed in a section of the cable which was exposed to open air in a handhole. The insulation had cracked and the conductor had fractured. This cable had been installed approximately five years. There was no apparent external damage to the cable except from deterioration and internal stresses. This is the second such fault in this cable.

FAA Obstruction Survey. The Coast and Geodetic Survey is resurveying the Arcata Airport and surrounding area for obstructions to navigation.

U. S. DEPARTMENT OF COMMERCE
Luther H. Hodges, *Secretary*

NATIONAL BUREAU OF STANDARDS
A. V. Astin, *Director*

THE NATIONAL BUREAU OF STANDARDS

The scope of activities of the National Bureau of Standards at its major laboratories in Washington, D.C., and Boulder, Colorado, is suggested in the following listing of the divisions and sections engaged in technical work. In general, each section carries out specialized research, development, and engineering in the field indicated by its title. A brief description of the activities, and of the resultant publications, appears on the inside of the front cover.

WASHINGTON, D. C.

Electricity. Resistance and Reactance. Electrochemistry. Electrical Instruments. Magnetic Measurements. Dielectrics. High Voltage.

Metrology. Photometry and Colorimetry. Refractometry. Photographic Research. Length. Engineering Metrology. Mass and Scale. Volumetry and Densimetry.

Heat. Temperature Physics. Heat Measurements. Cryogenic Physics. Equation of State. Statistical Physics.

Radiation Physics. X-ray. Radioactivity. Radiation Theory. High Energy Radiation. Radiological Equipment. Nucleonic Instrumentation. Neutron Physics.

Analytical and Inorganic Chemistry. Pure Substances. Spectrochemistry. Solution Chemistry. Standard Reference Materials. Applied Analytical Research. Crystal Chemistry.

Mechanics. Sound. Pressure and Vacuum. Fluid Mechanics. Engineering Mechanics. Rheology. Combustion Controls.

Polymers. Macromolecules: Synthesis and Structure. Polymer Chemistry. Polymer Physics. Polymer Characterization. Polymer Evaluation and Testing. Applied Polymer Standards and Research. Dental Research.

Metallurgy. Engineering Metallurgy. Microscopy and Diffraction. Metal Reactions. Metal Physics. Electrolysis and Metal Deposition.

Inorganic Solids. Engineering Ceramics. Glass. Solid State Chemistry. Crystal Growth. Physical Properties. Crystallography.

Building Research. Structural Engineering. Fire Research. Mechanical Systems. Organic Building Materials. Codes and Safety Standards. Heat Transfer. Inorganic Building Materials. Metallic Building Materials.

Applied Mathematics. Numerical Analysis. Computation. Statistical Engineering. Mathematical Physics. Operations Research.

Data Processing Systems. Components and Techniques. Computer Technology. Measurements Automation. Engineering Applications. Systems Analysis.

Atomic Physics. Spectroscopy. Infrared Spectroscopy. Solid State Physics. Electron Physics. Atomic Physics.

Instrumentation. Engineering Electronics. Electron Devices. Electronic Instrumentation. Mechanical Instruments. Basic Instrumentation.

Physical Chemistry. Thermochemistry. Surface Chemistry. Organic Chemistry. Molecular Spectroscopy. Molecular Kinetics. Mass Spectrometry.

Office of Weights and Measures.

BOULDER, COLO.

Cryogenic Engineering Laboratory. Cryogenic Equipment. Cryogenic Processes. Properties of Materials. Cryogenic Technical Services.

CENTRAL RADIO PROPAGATION LABORATORY

Ionosphere Research and Propagation. Low Frequency and Very Low Frequency Research. Ionosphere Research. Prediction Services. Sun-Earth Relationships. Field Engineering. Radio Warning Services. Vertical Soundings Research.

Radio Propagation Engineering. Data Reduction Instrumentation. Radio Noise. Tropospheric Measurements. Tropospheric Analysis. Propagation-Terrain Effects. Radio-Meteorology. Lower Atmosphere Physics.

Radio Systems. Applied Electromagnetic Theory. High Frequency and Very High Frequency Research. Modulation Research. Antenna Research. Navigation Systems.

Upper Atmosphere and Space Physics. Upper Atmosphere and Plasma Physics. Ionosphere and Exosphere Scatter. Airglow and Aurora. Ionospheric Radio Astronomy.

RADIO STANDARDS LABORATORY

Radio Physics. Radio Broadcast Service. Radio and Microwave Materials. Atomic Frequency and Time-Interval Standards. Millimeter-Wave Research.

Circuit Standards. High Frequency Electrical Standards. Microwave Circuit Standards. Electronic Calibration Center.


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